DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)
13.B Small Business Technology Transfer (STTR) Program
Proposal Submission Instructions

1.1 Introduction:

DARPA's mission is to prevent technological surprise for the United States and to create technological surprise for its adversaries. The DARPA SBIR and STTR Programs are designed to provide small, high-tech businesses and academic institutions the opportunity to propose radical, innovative, high-risk approaches to address existing and emerging national security threats; thereby supporting DARPA's overall strategy to bridge the gap between fundamental discoveries and the provision of new military capabilities.

The responsibility for implementing DARPA's Small Business Technology Transfer (STTR) Program rests with the Small Business Programs Office.

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
Attention: DIRO/SBPO
675 North Randolph Street
Arlington, VA 22203-2114
(703) 526-4170
Home Page http://www.darpa.mil/Opportunities/SBIR_STTR/SBIR_STTR.aspx

Offerors responding to the DARPA topics must follow all the instructions provided in the DoD Program Solicitation. Specific DARPA requirements in addition to or that deviate from the DoD Program Solicitation are provided below and reference the appropriate section of the DoD Solicitation.

SPECIFIC DARPA REQUIREMENTS

The solicitation has been EXTENSIVELY rewritten and follows the changes of the STTR reauthorization. Please read the entire DoD solicitation and DARPA instructions carefully prior to submitting your proposal. Please go to http://content.govdelivery.com/bulletins/gd/USSBA-4cada5# to read the STTR Policy Directive issued by the Small Business Administration.

3.0 DEFINITIONS

3.4 Export Control

The following will apply to all projects with military or dual-use applications that develop beyond fundamental research (basic and applied research ordinarily published and shared broadly within the scientific community):

(1) The Contractor shall comply with all U. S. export control laws and regulations, including the International Traffic in Arms Regulations (ITAR), 22 CFR Parts 120 through 130, and the Export Administration Regulations (EAR), 15 CFR Parts 730 through 799, in the performance of this contract. In the absence of available license exemptions/exceptions, the Contractor shall be responsible for obtaining the appropriate licenses or other approvals, if required, for exports of (including deemed exports) hardware, technical data, and software, or for the provision of technical assistance.

(2) The Contractor shall be responsible for obtaining export licenses, if required, before utilizing foreign persons in the performance of this contract, including instances where the work is to be performed on-site

at any Government installation (whether in or outside the United States), where the foreign person will have access to export-controlled technologies, including technical data or software.

(3) The Contractor shall be responsible for all regulatory record keeping requirements associated with the use of licenses and license exemptions/exceptions.

(4) The Contractor shall be responsible for ensuring that the provisions of this clause apply to its subcontractors.

Please visit http://www.pmddtc.state.gov/regulations_laws/itar.html for more detailed information regarding ITAR requirements.

3.5 Foreign National
ALL offerors proposing to use foreign nationals MUST follow Section 5.4.c.(8) of the DoD Program Solicitation and disclose this information regardless of whether the topic is subject to ITAR restrictions.

4.0 PROPOSAL FUNDAMENTALS

4.6 Classified Proposals
DARPA topics are unclassified; however, the subject matter may be considered to be a "critical technology" and therefore subject to ITAR restrictions. See **Export Control** requirements below in Section 3.3.

4.10 Debriefing
DARPA will provide a debriefing to the offeror in accordance with FAR Subpart 15.5. The notification letter will provide instructions for requesting a proposal debriefing. Small Businesses will receive a notification for each proposal submitted. Please read each notification carefully and note the proposal number and topic number referenced. All communication from the DARPA will originate from the sbir@darpa.mil e-mail address. Please white-list this address in your company's spam filters to ensure timely receipt of communications from our office.

Notification of Proposal Receipt
After the solicitation closing date, the person listed as the "Corporate Official" on the Proposal Coversheet will receive an e-mail with instructions for retrieving a proposal acknowledgement receipt from the DARPA SBIR/STTR Information Portal.

Information on Proposal Status
Once the source selection is complete, the person listed as the "Corporate Official" on the Proposal Coversheet will receive an email with instructions for retrieving a letter of selection or non-selection from the DARPA SBIR/STTR Information Portal.

5.0 PHASE I PROPOSAL

A Phase I Cost Volume ($100,000 maximum) must be submitted in detail online via the DoD SBIR/STTR submission system. Offerors are REQUIRED to use the online Cost Volume (available on the DoD SBIR/STTR submission site).

Technical Assistance
In accordance with the Small Business Act (15 U.S.C. 632), DARPA will authorize the recipient of a Phase I STTR award to purchase technical assistance services, such as access to a network of scientists and engineers engaged in a wide range of technologies, or access to technical and business literature available through on-line data bases, for the purpose of assisting such concerns in—

A. making better technical decisions concerning such projects;
B. solving technical problems which arise during the conduct of such projects;
C. minimizing technical risks associated with such projects; and
D. developing and commercializing new commercial products and processes resulting from such projects.

If you are interested in proposing use of a vendor for technical assistance, you must provide a cost breakdown under “Other Direct Costs (ODCs)” of the Cost Volume and provide a one page description of the vendor you will use and the technical assistance you will receive. The proposed amount may not exceed $5,000 and the description should be included as the LAST page of the Technical Volume. This description will not count against the 20-page limit and will NOT be evaluated. Approval of technical assistance is **not guaranteed** and is subject to review of the contracting officer.

Human or Animal Subject Research
DARPA discourages offerors from proposing to conduct Human or Animal Subject Research during Phase 1 due to the significant lead time required to prepare the documentation and obtain approval, which will delay the Phase 1 award.

5.3 (c) (6) Commercialization Strategy
DARPA is equally interested in dual use commercialization of STTR project results to the U.S. military, the private sector market, or both, and expects explicit discussion of key activities to achieve this result in the commercialization strategy part of the proposal. The discussion should include identification of the problem, need, or requirement relevant to a Department of Defense application and/or a private sector application that the STTR project results would address; a description of how wide-spread and significant the problem, need, or requirement is; and identification of the potential DoD end-users, Federal customers, and/or private sector customers who would likely use the technology.

Technology commercialization and transition from Research and Development activities to fielded systems within the DoD is challenging. Phase I is the time to plan for and begin transition and commercialization activities. The small business must convey an understanding of the preliminary transition path or paths to be established during the Phase I project. That plan should include the Technology Readiness Level (TRL) expected at the end of the Phase I. The plan should include anticipated business model and potential private sector and federal partners the company has identified to support transition and commercialization activities. In addition, key proposed milestones anticipated during Phase II such as: prototype development, laboratory and systems testing, integration, testing in operational environment, and demonstrations.

5.5 Phase I Proposal Checklist:
The following criteria must be met or your proposal may be REJECTED.

____1. Include a header with company name, proposal number and topic number to each page of your technical volume.
____2. Break out subcontractor, material and travel costs in detail. Use the "Explanatory Material Field" in the DoD Cost Volume worksheet for this information, if necessary.
____3. The base effort does not exceed $100,000.
____4. The technical volume does not exceed twenty (20) pages. Any page beyond 20 will be redacted prior to evaluations.
____5. Upload the Volume 1: Proposal Cover Sheet; Volume 2: Technical Volume; Volume 3: Cost Volume; and Volume 4: Company Commercialization Report electronically through the DoD submission site by 6:00 am ET, 25 September 2013.

____6. After uploading your file on the DoD submission site, review it to ensure that all pages have transferred correctly and do not contain unreadable characters. Contact the DoD Help Desk immediately with any problems.

6.0 PHASE I EVALUATION CRITERIA

The offeror's attention is directed to the fact that non-Government advisors to the Government may review and provide support in proposal evaluations during source selection. Non-government advisors may have access to the offeror's proposals, may be utilized to review proposals, and may provide comments and recommendations to the Government's decision makers. These advisors will not establish final assessments of risk and will not rate or rank offeror's proposals. They are also expressly prohibited from competing for DARPA SBIR or STTR awards in the SBIR/STTR topics they review and/or provide comments on to the Government. All advisors are required to comply with procurement integrity laws and are required to sign Non-Disclosure and Rules of Conduct/Conflict of Interest statements. Non-Government technical consultants/experts will not have access to proposals that are labeled by their proposers as "Government Only."

Please note that qualified advocacy letters will count towards the proposal page limit and will be evaluated towards criterion C. Advocacy letters are not required for Phase I. Consistent with Section 3-209 of DoD 5500.7-R, Joint Ethics Regulation, which as a general rule prohibits endorsement and preferential treatment of a non-federal entity, product, service or enterprise by DoD or DoD employees in their official capacities, letters from government personnel will NOT be considered during the evaluation process.

A qualified advocacy letter is from a relevant commercial procuring organization(s) working with a DoD or other Federal entity, articulating their pull for the technology (i.e., what need the technology supports and why it is important to fund it), and possible commitment to provide additional funding and/or insert the technology in their acquisition/sustainment program. If submitted, the letter should be included as the last page of your technical upload. Advocacy letters which are faxed or e-mailed separately will NOT be considered.

Limitations on Funding
DARPA reserves the right to select and fund only those proposals considered to be of superior quality and highly relevant to the DARPA mission. As a result, DARPA may fund multiple proposals in a topic area, or it may not fund any proposals in a topic area.

7.0 PHASE II PROPOSAL

All firms awarded a Phase I contract under this solicitation will receive a notification letter with instructions for preparing and submitting a Phase II Proposal and a deadline for submission. Visit http://www.darpa.mil/Opportunities/SBIR_STTR/SBIR_Program.aspx for more information regarding the Phase II proposal process.

10.0 CONTRACTUAL CONSIDERATIONS

Type of Funding Agreement (Phase I)

- DARPA Phase I awards will be Firm Fixed Price contracts.
- Companies that choose to collaborate with a University must highlight the research that is being performed by the University and verify that the work is FUNDAMENTAL RESEARCH.

- Companies are strongly encouraged to pursue implementing a government acceptable cost accounting system during the Phase I project to avoid delay in receiving a Phase II award. Visit www.dcaa.mil and download the "Information for Contractors" guide for more information.

Average Dollar Value of Awards (Phase I)
DARPA Phase I awards **shall not exceed $100,000**.

Publication Approval (Public Release)
NSDD 189 established the national policy for controlling the flow of scientific, technical, and engineering information produced in federally funded fundamental research at colleges, universities, and laboratories. The directive defines fundamental research as follows: "Fundamental research' means basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization, the results of which ordinarily are restricted for proprietary or national security reasons."

It is DARPA's goal to eliminate pre-publication review and other restrictions on fundamental research except in those exceptional cases when it is in the best interest of national security. Please visit http://www.darpa.mil/NewsEvents/Public_Release_Center/Public_Release_Center.aspx for additional information and applicable publication approval procedures. Visit http://dtsn.darpa.mil/fundamentalresearch/ to verify whether or not your award has a pre-publication review requirement.

10.7 Phase I Reports
All DARPA Phase I awardees are required to submit reports in accordance with the Contract Data Requirements List – CDRL and any applicable Contract Line Item Number (CLIN) of the Phase I contract. Reports must be provided to the individuals identified in Exhibit A of the contract.

DARPA STTR 13.B Topic Index

ST13B-001	Advanced Tools for Mammalian Genome Engineering
ST13B-002	Quantum Dot Mid-Wave Infrared Focal Plane Array
ST13B-003	Multiferroic Materials for RF Applications
ST13B-004	Data-Parallel Analytics on Graphics Processing Units (GPUs)

DARPA STTR 13.B Topic Descriptions

ST13B-001 TITLE: Advanced Tools for Mammalian Genome Engineering

TECHNOLOGY AREAS: Biomedical

OBJECTIVE: Improve the utility of Human Artificial Chromosomes (HACs) by developing new selectable metabolic markers for use in human cells, new high-fidelity methods for inserting DNA constructs of at least 50,000 base pairs (bp) in length into defined genomic loci, and new methodologies for facile intercellular genome transplantation.

DESCRIPTION: The ability to deliver exogenous DNA to mammalian cell lines is a fundamental tool in the development of advanced therapeutics, vaccines, and cellular diagnostics, as well as for basic biological and biomedical research. Current approaches to genetic engineering of mammalian cells rely on gene transfer methods such as plasmids, adenovirus-, lentivirus-, and retrovirus-vectors, cDNA, and minigene constructs. While these tools do provide the basic ability to deliver DNA to mammalian cells, there are several shortcomings associated with these state-of-the-art techniques. These include random DNA insertion into the host genome, variation in stable integration sites between cell lines, variation in the copy number and expression level of DNA that is delivered, limitations on the number and size of DNA constructs that can be delivered, and immunological responses to foreign DNA. Coupled with the significant time that is required to obtain useable engineered cell lines, these factors severely limit the scale and scope of research that can be performed and the applications that can be pursued.

One recently developed method for gene transfer that has the potential to address many of these shortcomings is the use of human artificial chromosomes (HACs). HACs possess several ideal properties, including very large DNA delivery capacities, stable, episomal maintenance within the cell, and lack of immunogenicity. Additionally, HACs can be designed to contain specific DNA sequences, such as integration sites, making them ideal for the creation of a completely engineerable platform. Although HACs show significant potential as a gene delivery vehicle, several technical hurdles remain that have prevented wide adoption of the technology. First, while HACs have the capacity to contain extremely large segments of DNA (potentially up to or surpassing 1,000,000 bp), currently molecular biology techniques are limiting in the amount of DNA that can be inserted into a DNA vector. It is typically difficult to insert more than 20,000 bp of DNA into a vector, negating much of the advantage that HACs possess as a delivery platform. Second, few selectable markers exist that are suitable for use in human cell lines, limiting the ability to screen for insertion or maintenance of the delivery platform. Third, methods utilized to transfer HACs between cell lines for vector delivery are extremely technically challenging, requiring highly specialized knowledge in order to be able to work with existing HAC vectors.

This solicitation is focused on improving the utility of HACs as a DNA delivery platform by developing technologies to address several key technical hurdles associated with current HAC vectors. These includes development of new selectable metabolic markers suitable for use in human cell lines, new high-fidelity methods for inserting DNA constructs at least 50,000 bp in length into defined genomic loci, and new methodologies for facile intercellular genome transplantation. A successful technology will be able to integrate into existing HAC vectors and will be capable of being readily transitioned to academic, government, and commercial researchers, all of whom rely on the ability to deliver DNA to mammalian cell lines.

PHASE I: Determine the technical feasibility of a new approach that focuses on addressing ONE of the following technical challenges:

a) The development of at least 3 new selectable markers based on metabolism for use in delivery of a HAC. Each metabolic marker should allow for the identification and selection of cells that have been transfected with the HAC vector, and should be broadly useful across human cell lines with minimal or no genetic manipulation of the host cell line required. Appropriate metabolic markers should be identified, methods for genetic selection should be detailed, and an analysis of cost for selection and maintenance of cell lines using each marker should performed.

b) The ability to stably integrate at least 50,000 bp of DNA into at least 10 different targeted genomic loci. Methods for insuring single copy integration at each site should be described and the ability to test for proper integration site targeting and specificity should be addressed. Performance goals of the new approach for maximum size limit of DNA that can be integrated and the percentage of correct cells that are achieved per transformation event should be established.

c) The development of a methodology for the rapid and facile shuttling of chromosomes or chromosome-sized DNA (e.g. HACs) between at least 10 different cell lines. The possibility of truncation, rearrangement, or fragmentation during chromosome transfer should be addressed and risk mitigation strategies described as appropriate. Performance goals for the frequency of chromosome transfer should be established.

For the selected challenge, develop an initial concept design and describe an approach for transitioning this technology from a laboratory benchtop to an established commercial protocol.

PHASE I deliverables will include: a technical report detailing experiments and results supporting the feasibility of the approach, and defined milestones and metrics as appropriate for the selected technical challenge. Also included with the PHASE I deliverables is a PHASE II plan for transitioning initial proof-of-concept experiments to protocols that are sufficiently robust and reproducible that they are viable as commercial technologies. The plan should include a detailed assessment of the potential path to commercialization, barriers to market entry, and collaborators or partners identified as early adopters for the new system.

PHASE II: Finalize the experimental approach from PHASE I and initiate the development and production of the technology to address the selected technical challenge. Establish appropriate performance parameters through experimentation to determine the efficaciousness, robustness, and fidelity of the approach being pursued. Develop, demonstrate, and validate the reagents and protocols necessary to meet the key metrics as defined for the selected technical challenge. PHASE II deliverables include a prototype set of reagents, a detailed technical protocol sufficient to allow replication of results in an outside laboratory, and valid test data, appropriate for a commercial production path.

PHASE III: The successful development of technologies for rapid introduction of large DNA vectors into human cell lines will enable the ability to engineer much more complex functionalities into human cell lines than are currently possible. This capability may support a number of DoD challenges, including the development of complex, multifunctional cell-based sensors for chem/biodefense applications, the simultaneous encoding of thousands of prophylactic or therapeutic antibodies for on-demand production of next-generation disease prevention and treatment, and the creation of complex cell lines that can be rapidly reconfigured to produce large volumes of a given vaccine. The biotechnology and pharmaceutical sectors are heavily reliant on the ability to rapidly manipulate and introduce DNA into human cell lines. The successful development of technologies that allow for improved human cell line generation has significant potential to rapidly transition to commercial use, enabling biologically based production of new protein-based therapeutics, new systems for vaccine development and production, and new platforms for small molecule drug screens that provide a more specific and sophisticated testing environment. Many of these applications are currently inaccessible due to the limitation of existing DNA delivery technologies and have the potential to be transformative if the technologies described herein are developed.

REFERENCES:
1) Y. Kazuki, H. Hoshiya, M. Takiguchi, S. Abe Y. Iida, M. Osaki, M. Katoh, M. Hiratsuka, Y. Shirayoshi, K. Hiramatsu, E. Ueno, N. Kajitani, T. Yoshino, K. Kazuki, C. Ishihara, S. Takehara, S. Tsuji, F. Ejima, A. Toyoda, Y. Sakaki, V. Larionov, N. Kouprina, M. Oshimura. "Refined human artificial chromosome vectors for gene therapy and animal transgenesis," Gene Ther. 18(4), p.384-93, 2011.

2) J.H. Kim, A. Kononenko, I. Erliandri, T.A. Kim, M. Nakano, Y. Iida, J.C. Barrett, M. Oshimura, H.

3) Masumoto, W.C. Earnshaw, V. Larionov, N. Kouprina. "Human artificial chromosome (HAC) vector with a conditional centromere for correction of genetic deficiencies in human cells," Proc Natl Acad Sci USA 108(50), p.20048-53, 2011.

4) S. Yamaguchi, Y. Kazuki, Y. Nakayama, E. Nanba, M. Oshimura, T. Ohbayashi. "A method for producing transgenic cells using a multi-integrase system on a human artificial chromosome vector," PLoS One 6(2), 2011.

5) M. Hiratsuka, N. Uno, H. Kurosaki, N. Imaoka, K. Kazuki, E. Ueno, Y. Akakura, M. Katoh, M. Osaki, Y. Kazuki, M. Nakagawa, S. Yamanaka, M. Oshimura. "Integration-free iPS cells engineered using human artificial chromosome vectors," PLoS One 6(10), 2011.

6) J.H. Bergmann, N.M.C. Martins, V. Larionoc, H. Masumoto, W.C. Earnshaw. "HACking the centromere chromatin code: insights from human artificial chromosomes," Chromosome Res, 20, p. 505-519, 2012.

7) M. Mlindenbaum, E. Perkins, E. Csonka, E. Fleming, L. Garcia, A. Greene, L. Gung, G. Hadlaczky, E. Lee, J. Leung, N. MacDonald, A. Maxwell, K. Mills, D. Monteith, C.F. Perez, J. Shellard, S. Stewart, T. Stodola, D. Vandenborre, S. Vanderbyl, H.C. Ledebur Jr., "A mammalian artificial chromosome engineering systems (ACE System) applicable to biopharmaceutical protein production, transgenesis and gene-based cell therapy," Nucleic Acids Research 32(21), 2004.

8) N. Kouprina, W.C. Earnshaw, H. Masumoto, V. Larionov, "A new generation of human artificial chromosomes for functional genomics and gene therapy," Cell Mol. Life Sci. 2012.

KEYWORDS: Bioengineering, Biology, Biotechnology, Cell Biology, Chromosome, Cytology, Gene Therapy, Synthetic Biology

ST13B-002 TITLE: <u>Quantum Dot Mid-Wave Infrared Focal Plane Array</u>

TECHNOLOGY AREAS: Materials/Processes, Sensors

OBJECTIVE: Develop a mid-wave infrared (MWIR) focal plan array (FPA) using quantum dots for next-generation night vision.

DESCRIPTION: Historically, night vision has provided the United States Armed Forces with an asymmetric tactical advantage in combat operations. However, the tradeoffs of low sensitivity (microbolometers), high power consumption (active cooling), or specialized consumables (liquid-nitrogen cooled HgCdTe) are a major technological hurdle to achieving low-power, low-cost and portable thermal night vision imaging.

Quantum dots have seen gradual improvements in reducing the band gap in recent years, making a highly-efficient and lower-cost detector material within the thermal infrared (IR) range potentially realizable [1]. High-efficiency of light detection from quantum dots results from the large extinction coefficient induced by quantum confinement [2], creating high-sensitivity without the need for external cooling, and thus reducing weight, size and power consumption. Current epitaxially-grown IR camera detectors cost >$10,000, while the projected cost of quantum dot-enabled detectors is $100, which could enable wider deployment of night vision technology to warfighters as well as low-power surveillance units. Beyond decreased detector cost, quantum dots may be amenable to facile fabrication techniques, such as spin coating, which could further decrease device costs [3].

Significant technical and market challenges exist in transitioning these recent, laboratory-quality quantum dots into device-ready materials that can be fabricated into focal plane arrays; material quality must be improved to enhance intrinsic and extrinsic quantum efficiency; manufacturing scalability and batch-to-batch consistency must be demonstrated; integrating wet solution processing methods with the control and readout structure; fabrication of a detector of comparable size to a commercial focal plane array. Proposers are free to formulate any approach that will contribute to the goal of making a low-cost, high-sensitivity MWIR FPA based on quantum dots.

PHASE I: Develop a design plan to fabricate and incorporate quantum dots into a focal plane array. The device must conform in size, shape and power requirements to existing commercial infrared focal plane array. Characterize the expected performance of this focal plane array including spectral sensitivity, resolution and projected cost. Show the feasibility of one or more critical elements of this approach through a lab demonstration. PHASE I deliverables will include a design review simulating device performance and a report presenting plans for PHASE II.

PHASE II: Construct and demonstrate the operation of a prototype quantum dot focal plane array validating the device performance outlined in PHASE I. The Transition Readiness Level to be reached is 5: Component and/or bread-board validation in relevant environment.

PHASE III: High-sensitivity quantum dot-based solutions will enable widespread deployment of night vision sensors across many platforms including small UAVs, helmet-mounted sensors, night vision goggles, security cameras, guided missile platforms and personnel vehicles. These low cost sensors will help maintain a tactical nighttime operations advantage. Commercial applications include the development of low-cost infrared cameras for private security and automotive applications.

REFERENCES:

1) S. Keuleyan, E. Lhuillier and P. Guyot-Sionnest, "Synthesis of colloidal HgTe quantum dots for narrow mid-IR emission and detection," Journal of the American Chemical Society, vol. 13.3, pp. 16422-16424, 2011.

2) I. Moreels, K. Lambert, D. De Muynck, F. Vanhaecke, D. Poelman, J. C. Martins, G. Allan and Z. Hens, "Composition and Size-Dependent Extinction Coefficient of Colloidal PbSe Quantum Dots," Chem. Mater., vol. 19, pp. 6101-6106, 2007.

3) G. Konstantatos, I. Howard, A. Fischer, S. Hoogland, J. Clifford, E. Klem, L. Levina and E. H. Sargent, "Ultrasensitive solution-cast quantum dot photodetectors," Nature, vol. 442, no. 7099, pp. 180-183, 2006.

KEYWORDS: quantum dots, mid-wave infrared, focal plane array, detector, night vision, thermal imaging

ST13B-003 TITLE: Multiferroic Materials for RF Applications

TECHNOLOGY AREAS: Materials/Processes, Electronics

OBJECTIVE: Demonstrate RF/microwave devices, components, and circuits based on multiferroic composite structures. Design discrete devices for radio and radar with a new tunability feature that adds to the performance over conventional RF/microwave components by leveraging the voltage-tunable frequency response of multiferroics. Demonstrate voltage tunable devices with performance equal to or better than state-of-the-art circuits.

DESCRIPTION: Multiferroic composites demonstrate a unique ability to control their ferromagnetic resonance (FMR) by applying an electric field that causes a shift in their FMR frequency. Multiferroic materials consist of strain-coupled ferromagnetic and ferroelectric phases resulting in a magneto-electric coupling between the two materials. This magneto-electric coupling mechanism has an electrostatically-controllable magnetization, a feature that can enable an entirely new family of RF components and circuits where frequency and bandwidth are electrically tunable.

RF/microwave multiferroic components such as tunable filters, duplexers, isolators, antennas and phase shifters are just a few examples of drop-in replacements, although entirely new devices, components and architectures are conceivable. Tunability is a feature added to the normal performance of an RF component. Multiferroic components with voltage tunability should perform at least as well as its non-multiferroic counterpart. In this way, tunability becomes a feature added to the RF/microwave designer’s toolbox.

Frequency agile devices have been fabricated from many combinations of electrostrictive and magnetostrictive materials. However these devices have tended to be bulky, slow, consume excess energy, and perform within a narrow band of frequencies. For instance, BST-based tunable filters operating in the wireless 1.6-2.0GHz band have published results of 10dB return loss and 4dB insertion loss with a 25% tuning range using a rather large 0-200VDC tuning voltage. X-band (8-10GHz) BST tunable filters have demonstrated 15dB return loss, 8dB insertion loss, and a 23% tuning range using 0-90VDC. By comparison, commercially-available, off-the-shelf filters offer better than 3dB insertion loss and 20dB return loss. Multiferroic device performance must exceed current commercial capabilities to economically viable while providing new capabilities for more demanding Defense applications which may have to deal with countermeasures. Multiferroic solutions having a highly-tunable ferromagnetic resonance frequency should offer >70dB dynamic range in addition to meeting commercial component performance. Multiferroic phase shifters could conceivably have -180 to +180 degrees of phase shift tunable from 900 MHz to 6 GHz with an instantaneous bandwidth of 20 MHz.

The availability of such components would dramatically transform the approach towards designing military RF/microwave radios and radars while also advancing the competitiveness of the U.S. electronics industry. Highly innovative and creative approaches, concepts and solutions based on multiferroic composites and their unique features are especially sought. It is highly desirable to develop manufacturing processes that enable commercial adoption of multiferroic devices by commercial vendors. A commercialization plan including adoption by RF/microwave component suppliers is encouraged. Recent advancements in the fabrication of high-quality ferrimagnetic-ferroelectric stacks have made this the time to commercialize multiferroic RF components.

PHASE I: Demonstrate a proof-of-concept multiferroic-based voltage tunable device used as the basis of a building block for a radio or radar. The device should be optimized for realistic radio or radar applications (voltage tuning range, frequency tuning range, power handling, quality factor, temperature coefficient, etc.) and should provide maximum tunability in the military frequency band assignments of the communications or radar spectrum. In addition to achieving conventional state-of-the-art performance, the design should provide for frequency tunability using a low-voltage (~12 volt) DC power supply. The physical design and fabrication shall be based on multiferroic composites with accompanying modeling and analysis to design physical layout and prediction of the high-frequency performance. PHASE I deliverables will also include development of an initial concept design and RF models of the key aspects of the device. Elements of the multiferroic design may be bread-boarded and measured as validation of detailed analysis of the predicted RF performance. The project plan should define and develop key technological milestones such as performance modeling and simulation of the device.

PHASE II: Fabricate and demonstrate an operating prototype of a multiferroics-based building block used in a radio or radar architecture. For example, the building block may be a tunable filter for a radio, a phase shifter for a radar set, or a similar 50 ohm component. It should build on the device developed in PHASE I, or use as its foundation the materials processing developed in PHASE I. A detailed plan of action to design, fabricate and assemble all the necessary RF components should be provided and followed by testing and characterization of the RF building block. The results of the testing should be used to update the multiferroic design, modeling and simulation tools. The RF performance parameters to be expected from multiferroic materials should be established through experiments performed on the prototype. Circuits of interest include, but are not limited to phase shifters (-180 to +180 degrees, tunable in the band 900 MHz to 6 GHz) and filters with high Dynamic Range and broad tunability (>70 dB dynamic range, 50% of center frequency). Broad band piezoelectric amplifiers (Reference 14) with composite microstructures (reference 15) with efficiency of greater than 60%; and compact B-field antennas are also components of interest for this topic. For devices utilizing the tunable response of multiferroics for other proposed devices/circuits (i.e.: broad band amplifiers and compact antennas) comparable quantitative metrics must be stated. At the conclusion of PHASE II effort, the building block prototype should be at a Technology Readiness Level 5 (TRL-5) or above.

PHASE III: Millitary applications of this technology include radios and radar systems. Voltage tunable inductors allow design of frequency agile circuits while maintaining constant impedance. Specific radar applications include ground penetrating applications and low frequency arrays for airborne use. The technology represents radical innovation for the wireless communication industry as well as radar systems. The U.S. commercial electronics community could benefit from a multiferroics fabrication process that is robust enough to be adopted for manufacturing. This would ultimately lead to monolithic integration of multiferroic materials with conventional silicon semiconductor processes. The multiferroic devices, components, circuits, and architectures proposed should have a development path leading to commercial adoption by mainstream RF component suppliers such as Mini-Circuits, Digi-Key, Newark, and similar established distributors. Such a development path would clearly show that multiferroics technology is ready for commercial electronics use.

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1) Cai N., Zhai J., Nan C.-W., Lin Y., Shi Z., Dielectric, ferroelectric, magnetic and magnetoelectric properties of multiferroic laminated composites, Phys. Rev., B 68, 224103 (1-7) (2003).

2) Y. Chen, J. Wang, J.Liu, J. Lou, N.X. Sun, C. Vittoria, V.G. Harris, Large electric field-induced magnetic field tunability in a laminated Ni2MnGa/PMN-PT multiferroic heterostructure, Appl. Phys. Letters, 93, 112502 (2008).

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ST13B-004 TITLE: Data-Parallel Analytics on Graphics Processing Units (GPUs)

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Explore the space of data-centric problems and algorithms that lend themselves to high-performance implementation on GPUs; develop a high-level language for easy programming of GPUs; and develop a product that can support real-time, quantitative analysis of a wide variety of data using the cost and energy efficient compute capabilities of GPUs and other relevant many core architectures.

DESCRIPTION: DOD is interested in exploiting trends in commercial technology for improved data analytics to provide improved real-time situation awareness capabilities essential to effective war fighting or for disaster response.

Commercial trends indicate that CPU clock's speeds have been essentially flat for the last decade. Continued speedups are only possible through many-core and distributed computing. General Purpose Graphics Processing Units (GPGPUs) are high-performance, general purpose, data-parallel processing architectures. Today's GPUs offer Teraflops speeds over thousands of stream cores [1]. Even in high end supercomputers such as Titan [2], much of the Petaflop speed is derived by GPUs hosted in its many compute nodes. Even mainstream CPUs feature increasingly powerful GPU components [11-12].

GPUs have been highly successful in gaming technology and have become nearly universal in mobile devices, tablets, and laptops in their role as graphics processors and GIS platforms. However, high development costs, limited interoperability with existing software ecosystems, and limited access to expert programmers have restricted the use of GPUs by a wider audience. Further, algorithms and data with non-local memory access patterns, such as graph processing, require special treatment to create efficient algorithms with coalesced memory access patterns on the GPU.

Industry has recognized the need for scalable, easy-to-use data-centric platforms as key drivers for innovation. This has led to a variety of scalable, open-source, and data-centric architectures. Tools such as Map/Reduce and Pregel (graph processing) enable scalability, but are not always efficient. Other approaches to scalable data-centric architectures offering high-level abstractions include programmable pipelines and databases. While expressing a desired analytic maybe easier in a given framework, there is often a best-in-class algorithm that could be orders of magnitude more efficient than a general purpose approach, for a given underlying hardware. Further, different algorithms may be required for GPU and CPU hardware. An opportunity exists to explore the relationship between these data-centric abstractions, and ways in which optimal programs could be derived.

A number of efforts are underway exploring how GPUs can be integrated into general purpose programming languages and environments [5-9]. However, these approaches fail to systematically accommodate the core algorithms that bring out the best performance of the underlying hardware and put programmers in the position of attempting to optimize for a complex technology outside of their expertise.

This STTR seeks research on exploring and characterizing the space of data-centric problems, and analytics and algorithms that lend themselves to high-performance implementation on GPUs. In addition, research is sought in developing a high-level language for easy programming of GPUs. Challenges include design of code from the outset to primarily run on the GPU (e.g., prefix scan, compact, allocate, hash tables [3]); identifying high-level data-centric abstractions and development of a language to express them; and, finally, translating user programs to execute efficiently on underlying hardware with runtime workload. Research must address choice of configurations to optimize for latency, throughput, or tradeoff completeness for characterized accuracy. Also of interest is the division of computation between device and cloud when deploying in environments with limited connectivity, bandwidth, or power. Finally, the STTR seeks development of a product that can support real-time, quantitative analysis of a wide variety of data using the cost and energy efficient compute capabilities of GPUs and other relevant many core architectures.

An example data-centric problem is the space of graphs where GPUs are not traditionally thought to be relevant due to the data dependent scheduling of threads and difficulties in identifying redundant work without sacrificing throughput. However, recent research [4] has shown that graph traversal can be parallelized efficiently on the GPU. Earlier research [11] has demonstrated that Map/Reduce may be realized efficiently on GPUs, but extensions are required to handle some problems efficiently. Effort is required to identify tradeoffs among different highly parallel architectures to understand how work can be efficiently scheduled on different architectures, to identify key primitives for data-parallel hardware and abstractions that will increase the reusability of data parallel algorithms, and to translate high level user programs to efficient, low-level and hardware specific algorithms.

The proposed approaches should provide significant advantages over current technologies: 1) technology enabling a widely available, low-cost, data-centric computing infrastructure to allow widespread use of data analytics in small and large enterprises, 2) ability to write new analytics easily to run efficiently on highly parallel and distributed systems, and 3) ability to easily incorporate new hardware and new algorithms into existing analytics.

PHASE I: Develop an initial concept design and model key elements for a data-centric processing architecture leveraging GPUs and many-core computing platforms. Identify a set of data-centric problems that are likely to be efficient on GPUs, and implement a set of algorithms characterizing their structure and its relation to efficiency gains on a given underlying hardware. PHASE I deliverables will include a technical report and brief describing the plan of approach and key technological achievements for the development of a prototype system.

PHASE II: Develop a high-level language for GPU programming, and implement translation of user programs to execute efficiently against the underlying hardware and the actual runtime workload. Construct and demonstrate the operation of a prototype in an operationally relevant environment. In parallel to this development, develop, test, and demonstrate validity and generalizability of GPU accelerated analytics for multiple applications. Required PHASE II deliverables will include the prototype and examples of GPU accelerated applications based on the prototype, and a technical report and brief describing 1) the system design and test results, 2) sample applications, 3) and feasibility of use in future commercial and/or military applications.

PHASE III: A portable device offering low-cost and high-performance on a wide range of data-centric analytics would benefit the military broadly. Soldiers with access to improved analytics on the battlefield would have improved real-time situation awareness capabilities essential to effective war fighting or evolving disaster response scenarios. Situated analytics could synthesize data from a unit and the operational theatre, delivering answers and analytics that bear on the immediate problem of the war fighter. GPU accelerated analytics could improve the capabilities of reach back information and analysis systems, providing faster response times and handling larger workloads. The increased compute per square foot, compute per pound, and compute per watt would benefit resource-constrained environments. Many commercial entities would have interest in a low-cost, high-performance, easily customized, scalable analytics. Potential marketplace applications exist in marketing, gaming, medicine, and many related fields.

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KEYWORDS: GPUs, many-core, distributed computing, high-level languages